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centrations are calculated in the usual manner from conductance measurements.

In conclusion it may be noted that the value of E/n_c in equation (1) when multiplied by F, the value of the faraday, represents the maximum work or free-energy change attending the transfer of one equivalent of salt from one concentration to the other, and that therefore E_L may be calculated from any of the properties related to osmotic pressure, such as freezing-point. This free energy-change may also be obtained directly from electromotive force measurements of cells without transference of the type;Ag, AgCl (solid) + KCl (0.1n), $K(Hg)_x$ – $K(Hg)_x$, AgCl (solid) + KCl (0.01n), Ag, investigated by MacInnes and Parker.

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[1] See for instance, Jahn, *Zs. physik. Chem.* **33**, 545 (1900); Tolman and Ferguson, *J. Amer. Chem. Soc.* **34**, 232 (1912); MacInnes and Parker, *J. Amer. Chem. Soc.* **37**, 1445 (1915).

[2] *J. Amer. Chem. Soc.* **33**, 1454 (1911).

A STATISTICAL STUDY OF THE VISUAL DOUBLE STARS IN THE NORTHERN SKY

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The double star survey, initiated in April, 1899,[1] has now been completed to –14° Declination for the winter sky and to –22° Declination for the summer sky. This is about as far south as atmospheric conditions make it desirable to extend the survey at Mount Hamilton.

The original plan contemplated the examination with one of the refracting telescopes of the Lick Observatory of all stars as bright as 9.0 magnitude in the *Bonn Durchmusterung*, the identification of all previously known double stars, and the cataloguing of any new pairs, not exceeding 5″.00 in angular separation. Limits must be imposed in work of this character, and those chosen, while necessarily arbitrary, were selected after careful study as being liberal enough for the purpose in mind, which was the accumulation of data for a statistical study of the number and distribution of the visual double stars.

The survey has yielded 4300 new double stars, 1328 discovered by Prof. W. J. Hussey, the others by the writer. Twenty-eight of these have angular separation slightly exceeding 5″.00; 3199, or 74.4% of the whole number, fall within the limit 2″.00, and 1280 (29.8%), within the limit 0″.50. The distance limit adopted has thus been carefully observed, but for various reasons many stars fainter than the limit 9.0 were examined with the result that several hundred of our discoveries are fainter than this magnitude. It may develop that the most important contribution made by the survey, possibly the only one of permanent value, is this great addition to the number of known close visual binaries. Nevertheless, the statistical study has been the object which I have held definitely in mind from the beginning and I have regarded discovery as incidental.

The present paper gives the results from a partial statistical study for the northern half of the sky, the data including all visual double stars (as distinguished from spectroscopic binaries) as bright as 9.0 B. D. magnitude which fall within the limits set by my 'working definition' of a double star.[2] In all there are 5400 such pairs north of the celestial equator, 2823 of which were discovered in the course of the Lick Observatory survey. It is not claimed that this number is exhaustive, but it may fairly be said that it represents the capacity of the combination of telescope and observer under *average good observing conditions at Mount Hamilton.* Unfortunately the data are not strictly homogeneous, for part of the survey was carried out with the 12-inch refractor. A study of the relative efficiency of the 12-inch and 36-inch refractors in double star discovery leads to the conclusion that, if the entire work had been done with the latter telescope, about 250 additional pairs would have been discovered in the northern hemisphere.

According to Seeliger's count, the *Bonn Durchmusterung* contains 100,979 stars as bright as 9.0 magnitude north of the celestial equator; 5400 of these, or one in 18.7 on the average, have actually been found to be double within the chosen limits. If we add only 200 more pairs the ratio is increased to 1 in 18.03. We may therefore conclude that *at least one in every eighteen, on the average, of the stars as bright as 9.0 magnitude in the northern half of the sky is a double star visible with the 36-inch telescope.*

Table I shows the distribution of these double stars in galactic latitude by magnitude classes, the arguments, for convenience of comparison, being those adopted by Seeliger[3] in his discussion of the B. D. stars. The zones are 20 wide, the first extending from the north galactic pole to +70°, the fifth from +10 to −10 galactic latitude. Zone IX, touching the south galactic pole, lies entirely south of the celestial equator. The progressive increase in numbers in every magnitude class as we approach Zone V from the north or from the south was to be expected, for it is well known that the stars as a whole show a similar distribution. When, however, we compare the results with Seeliger's tabulation for all the B. D. stars to 9.0, we find that the frequency curves of double stars of every magnitude class rise to sharper maxima in the Milky Way than do the corresponding curves of the stars in general.

This is most strikingly exhibited in Table II which gives the percentage of double stars in the Milky Way zone, the 20° zone on either side of it, the area north of +30° and that south of −30° galactic latitude.

TABLE I

THE DISTRIBUTION OF DOUBLE STARS BY MAGNITUDE CLASSES AND ZONES OF GALACTIC LATITUDE

ZONE	MAG. TO 6.5	MAG. 6.6–7.0	MAG. 7.1–7.5	MAG. 7.6–8.0	MAG. 8.1–8.5	MAG. 8.6–9.0	TOTAL
I	19	13	14	29	40	84	199
II	43	28	50	68	114	193	496
III	60	43	56	79	148	254	640
IV	96	54	81	132	232	401	996
V	121	88	133	249	376	653	1620
VI	84	51	81	134	221	395	966
VII	28	23	18	54	90	154	367
VIII	7	6	5	12	31	55	116
Total	458	306	438	757	1252	2189	5400

Areas of all galactic latitudes were examined in winter, others are as in summer; the larger part of the work done with the 12-inch telescope lies between +27° and −3° galactic latitude; nearly the entire area south of −3°, and also the high northern galactic latitudes, were surveyed with the 36-inch refractor. The apparent increase in percentage in the Milky Way zone is therefore not due to the use of different telescopes nor to any other peculiarity in the collection of the data, and we must conclude that *close visual double stars are relatively more numerous in the Milky Way than elsewhere in the sky.*

TABLE II

PERCENTAGES OF DOUBLE STARS

GALACTIC LATITUDE	B. D. STARS TO 9.0	DOUBLE STARS	PERCENTAGE OF DOUBLE STARS
+90° to +30°	26948	1335	4.95
+30 to +10	19355	996	5.15
+10 to −10	26477	1620	6.13
−10 to −30	17831	966	5.13
−30 to −70	10368	483	4.66

I have tabulated the double stars in distance classes by steps of 0″.5 and find that the increased density toward the Milky Way is exhibited by stars of every class, though the percentages in Table II are most strongly affected by the close pairs because of their greater number.

Table III shows the relation between magnitude and angular separation. Since the progressive increase in the number of double stars as the angular distance diminishes is shown by stars of every magnitude class, it cannot be explained as merely a perspective effect, the more distant pairs appearing at smaller angles, for according to our present conceptions, stars of a given magnitude (e.g., from 8.6 to 9.0) are approximately at the same average distance from us. The relative angular separations of the double stars of this magnitude therefore reflect the relative linear distances between the components and it follows that *visual double stars as a rule revolve in relatively small orbits.*

The spectral classification of the majority of the 5400 stars under discussion is at present unknown. I have compared the list with the Draper Catalogue in volume 50 of the *Harvard Annals*, thus securing the spectral data for the brighter stars, and Prof. E. C. Pickering and Miss Annie J. Cannon have been kind enough to compare the list of double stars north of +60° and that of the double stars in the first two hours of Right Ascension with the new Draper Catalogue now in course of preparation at Harvard, which is designed to extend to 9.0 magnitude. Combining the data from these three sources and excluding duplicates we have Table IV.

TABLE III

THE DISTRIBUTION OF DOUBLE STARS IN THE NORTHERN HEMISPHERE BY ANGULAR DISTANCE AND MAGNITUDE

DIST.	0″.00 TO 0.50	0″.51 TO 1.00	(0″.00) TO (1.00)	1″.01 TO 2.00	2″.01 TO 3.00	3″.01 TO 4.00	4.01 TO 5.00	5″.01 AND OVER
Mag. to 6.5	75	63	(138)	83	62	41	31	99
6.6 to 7.0	82	52	(134)	59	42	40	21	14
7.1 to 7.5	103	67	(170)	99	64	48	31	29
7.6 to 8.0	178	132	(310)	164	107	85	63	26
8.1 to 8.5	310	223	(533)	285	173	128	111	21
8.6 to 9.0	508	413	(931)	532	317	217	191	11
Total.......	1256	954	(2206)	1222	765	559	448	200

The distribution of these stars with respect to the galactic plane closely resembles that of the stars in general; Classes B and A crowd toward that plane, classes F, G and K show a more uniform distribution. The totals show how marked is the preference of the visual double stars for Classes A and F. It may be added that 46 of the 83 Class B stars belong to the subclasses B8 and B9 and that 104 of the 124 Class K stars are marked 'K' or 'K0.' Clearly, *close visual double stars are rare among stars of either very early or very late spectral class.* This confirms my conclusion, in 1910,[4] based on an analysis of the spectral classification of 164 of the more rapidly moving binary stars on my observing program.

The ten stars of Classes M and Oe5 are obviously exceptional, and the number is too small for any discussion of value. The following points however may be noted: The stars are all bright; the proper motions are very small; orbital motion has been observed in only one of them (η *Geminorum*), and in this system it is very slow; the companion in each instance is much fainter than its primary, and the angular separation between the components is neither very small nor very large. Probably they are all very distant.

TABLE IV

SPECTRAL CLASSIFICATION OF DOUBLE STARS

ZONE	SPECTRAL CLASS						
	B	A	F	G	K	M	Oe 5
I.............	0	8	4	2	3		
II.............	2	19	14	5	12		
III............	3	37	59	28	22		
IV............	18	81	68	45	26	1	
V.............	47	101	54	31	24	5	2
VI............	9	84	47	31	15	1	1
VII...........	3	19	33	16	14		
VIII..........	1	8	29	16	8		
Total........	83	357	308	174	124	7	3

The percentage of very close double stars—under $0''.50$—is considerably greater in Classes B, A and F than in Classes G and K, but the percentage of pairs over $2''.0$ is about the same in all classes except K, in which it is larger. To discuss the correlation between angular separation and spectral class we need further data. I hope to take up this question and others in a later paper.

The conclusions here presented of course apply only to the data upon which they rest, and, in view of the many warnings we have had against basing 'laws of nature' upon incomplete statistics, I refrain from any comment upon the bearing they may have upon current theories of the evolution of double star systems. It is my opinion that we have not yet sufficient knowledge of the facts to establish any theory with reasonable certainty.

[1] "On Double Stars," R. G. Aitken, *San Francisco, Pub. Astr. Soc. Pac.*, **16**, 235 (1904).

[2] "The Definition of the Term Double Star," R. G. Aitken, *Ast. Nachr.*, **188**, 281 (1911).

[3] "Ueber die Vertheilung der Sterne auf der nördlichen Halb-kugel . . . ," H. Seeliger, *München, Sitz. Ber. Ak. Wiss.*, 1884, Heft 4.

[4] "Second Catalogue of Spectroscopic Binary Stars," W. W. Campbell, *Lick Obs. Bull.*, **6**, 41 (1910).